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CGA-362622 Antagonizes Annual Grass Control with Clethodim[1]

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Abstract: Field and greenhouse experiments were conducted to evaluate clethodim, CGA-362622, mixtures thereof, and sequential treatments for control of broadleaf signalgrass, fall panicum, goosegrass, and large crabgrass. In greenhouse experiments, clethodim alone provided 93 and 100% control of three- to four-leaf goosegrass at the low (105 g ai/ha) and high (140 g/ha) rates, respectively, whereas CGA-362622 did not control grasses in greenhouse or field experiments. Control of six- to eight-leaf goosegrass in the greenhouse with clethodim was 75% for the low rate and 89% for the high rate. Control of goosegrass in greenhouse studies was reduced at least 43 percentage points with CGA-362622 and clethodim at the high rate in mixture compared with control provided by clethodim at the high rate alone. When CGA-362622 and clethodim were applied in mixture in field studies, the effectiveness of the graminicide was decreased from > 97 to < 57% control for all annual grasses. Antagonism of clethodim activity was greater than that of the tank mixture when clethodim was applied 1 d after CGA-362622 on large crabgrass, goosegrass, and fall panicum. Clethodim applied 7 d before or after CGA-362622 controlled the four grass species as well as did clethodim applied alone. When CGA-362622 was applied to goosegrass alone, fresh weight accumulation stopped for a period of 4 d compared with untreated plants. Normal growth resumed after 4 d.

Nomenclature: CGA-362622, *N*-[(4,6-dimethoxy-2-pyrimidinyl)carbamoyl]-3-(2,2,2-trifluoroethoxy)-pyridin-2-sulfonamide sodium salt; clethodim; broadleaf signalgrass, *Brachiaria platyphylla* (Griseb.) Nash #[3] BRAPP; fall panicum, *Panicum dichotomiflorum* (L.) # PANDI; goosegrass, *Eleusine indica* (L.) Gaertn. # ELEIN; large crabgrass, *Digitaria sanguinalis* (L.) Scop. # DIGSA.

Additional index words: Antagonism, growth analysis, orthogonal contrasts.

Abbreviations: ALS, acetolactase synthase (EC 4.1.3.18); DAT, days after treatment; POST, postemergence.

INTRODUCTION

Broadleaf signalgrass, fall panicum, goosegrass, and large crabgrass are among the most common and troublesome grass weeds in U.S. cotton (*Gossypium hirsutum* L.) and among the most troublesome annual grass weeds in agriculture (Byrd 2000; Dowler 1998). Inadequate control of these weed infestations can reduce cotton yields and cotton fiber quality (Byrd 2000). Typically, these and other grass and broadleaf weeds are prevalent together in cotton fields. For this reason, optimum application timings for selective herbicides having either grass or broadleaf weed activity often coincide.

CGA-362622 is a sulfonylurea herbicide under development for use in cotton and for postemergence (POST) control of broadleaf weeds, particularly sicklepod [*Senna obtusifolia* (L.) Irwin and Barneby] and common ragweed (*Ambrosia artemisiifolia* L.) (Hudetz et al. 2000; Wilcut et al. 2000). Clethodim is a graminicide registered on cotton, peanut (*Arachis hypogaea* L.), and soybean [*Glycine max* (L.) Merr.] (Anonymous 2001). The effectiveness of clethodim on annual and perennial grass weeds and CGA-362622 on numerous broadleaf weeds makes the use of these herbicides applied POST either sequentially or in tank mixtures a likely option for broad spectrum weed control in cotton.

However, acetolactate synthesis (ALS) inhibitors such as imidazolinone, pyrimidylbenzoate, and sulfonylurea herbicides, including chlorimuron, imazethapyr, pyrithiobac, and thifensulfuron, have antagonized cyclohexanedione herbicides (clethodim and sethoxydim),

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[3] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

causing a reduction in grass control (Culpepper et al. 1999; Ferreira and Coble 1994; Ferreira et al. 1995; Foy and Witt 1992; Holshouser and Coble 1990; Minton et al. 1989; Myers and Coble 1992; Snipes and Allen 1996; Vidrine et al. 1995). Therefore, the objectives of this study were (1) to determine the potential for antagonism on four annual grasses with mixtures of CGA-362622 and clethodim, (2) to determine whether antagonism in mixtures can be avoided by applying CGA-362622 and clethodim separately, and (3) to evaluate goosegrass growth as influenced by CGA-362622.

MATERIALS AND METHODS

Methods Common for Field and Greenhouse Experiments. The experiments were a randomized complete block design with three replications of treatments. Clethodim and CGA-362622 were applied alone, in mixture, and sequentially at 1-, 3-, 7-, or 14-d intervals. All initial herbicide applications were made on the first day of the experiment. The sequential treatments followed at the specified intervals for a total application interval of 14 d. Each experiment included a nontreated control for comparative purposes. Two rates of clethodim were used in greenhouse experiments, 105 and 140 g/ha. Clethodim was applied at 140 g/ha in field experiments. CGA-362622 was applied at 5 g/ha in both greenhouse and field experiments. Crop oil concentrate[4] at 1% (v/v) was included in all mixtures. Visual estimates of grass control were recorded based on a scale of 0% (no control) to 100% (plant death) 17 to 23 d after the final herbicide application (Frans et al. 1986).

Greenhouse Experiments. Ten to twelve goosegrass seed were planted in 500-ml pots filled with a commercial potting mix.[5] On emergence, plants were thinned to 3 plants/pot. Plants were grown in approximate day and night temperatures of 30 and 17 C, respectively, and were surface-irrigated as needed. All pots received 10 ml of a 13 g/L commercial greenhouse fertilizer[6] solution at emergence and 14 d later. Experiments were performed on goosegrass at the three- to four- and six- to eight-leaf stages. The experiment was repeated for each goosegrass size. Applications of herbicides were made in a spray chamber, with a single 8001EVS flat-fan nozzle[7] calibrated to deliver 140 L/ha at 297 kPa.

Field Experiments. Field experiments were conducted in two separate fields at both the Clayton Research Station and the Upper Coastal Plain Research Station near Rocky Mount, NC, in 2000. Soils were a Norfolk loamy sand (fine-loamy, siliceous, thermic Typic Paleudults), with 1.8% organic matter and a pH of 5.5 to 5.7, at Clayton and a Conetoe loamy sand (loamy, mixed, thermic Arenic Hapludults), with 1.1% organic matter and a pH of 5.6 to 5.8, at Rocky Mount. Each test was placed in field areas where grass populations were > 20 plants/m^2. Grass heights were 20 to 25 cm at the time of initial herbicide applications. Grasses were 30 to 60 cm tall at the 14-d treatments. Plots were 3 m wide by 6.1 m long. Herbicides were applied using a CO_2-backpack sprayer calibrated to deliver a volume of 190 L/ha at 140 kPa through XR-11002VS spray nozzles.[7]

Growth Analysis. To evaluate goosegrass growth as influenced by CGA-362622, 10 to 12 goosegrass seed were planted in 500-ml pots filled with a commercial potting mix. On emergence, plants were thinned to 1 plant/pot. Plants were grown at approximate day and night temperatures of 30 and 17 C, respectively, and surface-irrigated as needed. All pots received 10 ml of a 13-g/L commercial greenhouse fertilizer solution on emergence and 14 d after emergence. Plants were blocked according to leaf number, which ranged from four to eight leaves. The experiment was a split-plot design with main plots arranged as a randomized complete block, with goosegrass treated with CGA-362622 and nontreated goosegrass as main plots and harvest timings as subplots in a split-plot design. The experiment had four replications. CGA-362622 was applied at 5 g/ha with nonionic surfactant[8] at 0.25% (v/v), using a spray chamber with a single 8001EVS flat-fan nozzle[7] calibrated to deliver 140 L/ha at 297 kPa. Plants were harvested on treatment and 2, 4, 6, and 8 d after treatment (DAT), and fresh weight in grams was recorded. The experiment was conducted twice over time.

Statistical Analysis. Field and greenhouse data, analyzed separately, were tested for homogeneity of variance by plotting residuals. Data from the control were removed from both field and greenhouse data to stabilize variance. An arcsine square-root transformation did not

[4] Crop oil concentrate, Agri-Dex (83% paraffin-base petroleum oil and 17% surfactant blend). Helena Chemical Co., 5100 Poplar Avenue, Memphis, TN 38137.

[5] Potting media, Metro-Mix 220. Scotts-Sierra Horticultural Products Co., 14111 Scottslawn Road, Marysville, OH 43041.

[6] Fertilizer, Peters Professional 20-20-20. Scotts-Sierra Horticultural Products Co., 14111 Scottslawn Road, Marysville, OH 43041.

[7] Nozzles, TeeJet spray nozzles. Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60189.

[8] Nonionic adjuvant, Induce (90% alkyl aryl polyoxylkane ether and free fatty acids). Helena Chemical Co., 5100 Poplar Avenue, Memphis, TN 38137.

improve variance homogeneity, so nontransformed data were used in analysis and presentation for clarity.

Greenhouse data, separated by goosegrass growth stage, and field data were subjected to an analysis of variance using the general linear models procedure SAS, 1998. Sums of squares were partitioned to evaluate, in the case of greenhouse trials, CGA-362622 and clethodim mixtures, sequential applications thereof, clethodim rate, and trial replication. Field trials were partitioned to evaluate the effect of CGA-362622 and clethodim mixtures, sequential applications thereof, and location. Both experiment replication and location or trials were considered as random variables, and the main effects and interactions were tested by the appropriate mean square associated with the random variable (McIntosh 1983). Mean separations were performed using Fisher's protected LSD at P = 0.05.

The expected response for herbicide mixtures and sequential treatments was calculated according to Colby (1967). Expected and observed values were compared using the appropriate LSD value at the 5% level. If the observed response for the herbicide mixture or sequential application was either significantly less than or greater than the expected value, the combination was declared either antagonistic or synergistic, respectively. Mixtures or sequential applications were considered additive (i.e., no interaction) when differences between observed and expected responses were not significant (Hicks et al. 1998).

Growth analysis data were subjected to an analysis of variance using the general linear models procedure in SAS (1998), and sums of squares were partitioned to evaluate the effect of treatment and harvest timing. Data were log-transformed (base *n*) to compensate for the increasing variance with time. Study repetition was considered a random variable, and main effects and interactions were tested by the appropriate mean square associated with the random variable (McIntosh 1983). Regression analysis was used to describe the response of both untreated goosegrass and goosegrass treated with CGA-362622, and then orthogonal polynomial contrasts were used to compare the growth rates of treated and untreated plants during the intervals of 0 to 4 and 4 to 8 DAT.

RESULTS AND DISCUSSION

Greenhouse Studies. CGA-362622 alone did not control goosegrass in greenhouse studies (Table 1). Clethodim alone controlled 93 and 100% of three- to four-leaf goosegrass at the low (105 g/ha) and high (140 g/ha) rates, respectively. Control of six- to eight-leaf goosegrass with clethodim was 75% for the low rate and 89% for the high rate. Others have noted a decrease in grass control with clethodim as grass size increased or rate decreased (Askew et al. 2000; Culpepper et al. 1999).

Table 1. Interaction of CGA-362622 and application sequences of clethodim for control of goosegrass in greenhouse trials. Data are presented separately by plant growth stage and averaged over greenhouse trials.[a]

Clethodim rate	CGA-362622 rate	Goosegrass growth stage three–four leaf	Goosegrass growth stage six–eight leaf
g ai/ha	g ai/ha	%[c]	
0	5	0	0
105	0	93	75
105	5	43*	16*
140	0	100	89
140	5	57*	27*
105	5 (1 d)[b]	42*	21*
105	5 (3 d)	52*	32*
105	5 (7 d)	91	78
105	5 (14 d)	90	79
140	5 (1 d)	54*	30*
140	5 (3 d)	72*	42*
140	5 (7 d)	100	90
140	5 (14 d)	100	91
105 (1 d)	5	48*	24*
105 (3 d)	5	55*	29*
105 (7 d)	5	92	68*
105 (14 d)	5	92	77
140 (1 d)	5	54*	30*
140 (3 d)	5	72*	32*
140 (7 d)	5	100	84
140 (14 d)	5	100	89
LSD		4	4

[a] Crop oil concentrate at 1.0% (v/v) was included with all clethodim treatments.

[b] These values indicate the length of time (d) between sequential applications of CGA-362622 or clethodim.

[c] Means within a column separated according to Fisher's protected LSD (P = 0.05).

* Denotes antagonism, and no marking indicates an additive effect. Interactions were considered significant only if the differences between the observed and computed expected values (Colby 1967) exceeded the appropriate LSD.

Control of goosegrass in greenhouse studies (Table 1) was reduced by at least 43 percentage points with CGA-362622 and clethodim at the high rate in mixture (57% control for three- to four-leaf goosegrass, 27% control for six- to eight-leaf goosegrass), compared with control provided by clethodim alone at the high rate. Control of both sizes of goosegrass with mixtures of the two herbicides decreased with the reduction in the clethodim rate.

For sequential applications, the greatest reduction in grass control at both growth stages occurred when CGA-362622 was applied first followed by clethodim 1 d later (Table 1). Furthermore, reduced grass control was ob-

Table 2. Interaction of CGA-362622 and application sequences of clethodim for control of broadleaf signalgrass, fall panicum, goosegrass, and large crabgrass in field trials.[a]

Application sequence of clethodim[b]	Broadleaf signalgrass	Fall panicum	Goosegrass	Large crabgrass
	%[c]			
CGA-362622 alone[d]	0	0	0	0
14 d before	100	97	97	97
7 d before	99	99	97	98
3 d before	75*	74*	71*	75*
1 d before	48*	41*	32*	40*
Mixture	30*	31*	29*	37*
1 d after	31*	17*	22*	23*
3 d after	48*	54*	43*	47*
7 d after	96	95	93	94
14 d after	96	91*	86*	89*
Clethodim alone	100	99	97	98
LSD	6	7	7	6

[a] Data averaged over locations. Means within a column are separated according to Fisher's protected LSD ($P = 0.05$).

[b] Application sequence of clethodim relative to the application of CGA-362622.

[c] '*' denotes antagonism and no marking indicates an additive effect. Interactions were significant only if the differences between the observed and computed expected values (Colby 1967) exceeded the appropriate LSD.

[d] CGA-362622 was applied at 5 g ai/ha, and clethodim was applied at 140 g ai/ha. All herbicide mixtures included crop oil concentrate at 1.0% (v/v).

served when clethodim was applied within 3 d of CGA-362622 treatment regardless of growth stage. Antagonism also occurred when CGA-362622 was applied first to the larger goosegrass, followed by clethodim 7 d later, although no other 7-d sequential application reduced goosegrass control. No antagonism was observed in greenhouse studies when clethodim was applied first followed by CGA-362622 7 or 14 d later or when CGA-362622 was applied first followed by clethodim 14 d later.

Field Studies. CGA-362622 did not control broadleaf signalgrass, fall panicum, goosegrass, or large crabgrass in field studies (Table 2). Clethodim alone controlled broadleaf signalgrass, fall panicum, goosegrass, and large crabgrass at 100, 99, 97, and 98%, respectively. In past research, clethodim at 140 g/ha provided $>$ 90% control of broadleaf signalgrass, fall panicum, goosegrass, and large crabgrass (Jordan 1995; Myers and Coble 1992; Vidrine et al. 1995; York and Culpepper 2000).

Broadleaf signalgrass, fall panicum, goosegrass, and large crabgrass control in the field was less (30, 31, 29, and 37% control, respectively) when CGA-362622 and clethodim were applied in mixture than when clethodim was applied alone (Table 2). There was a difference between the predicted and observed control values for all grass weeds, indicating antagonism (Colby 1967). Other research has shown that CGA-362622 has antagonized other graminicides in a similar manner (Crooks et al. 2001).

Reduced grass control was observed in field studies when clethodim was applied within 3 d of CGA-362622 treatment (Table 2). For sequential applications, the greatest reduction in grass control occurred when CGA-362622 was applied first followed by clethodim 1 d later. When CGA-362622 was applied first followed by clethodim 1 d later, broadleaf signalgrass, fall panicum, goosegrass, and large crabgrass control was 31, 17, 22, and 23%, respectively. Antagonism of clethodim by CGA-362622 also occurred when clethodim was applied first followed 3 d later by CGA-362622 or when CGA-362622 was applied first followed by clethodim 3 d later. No antagonism was observed when clethodim was applied first followed by CGA-362622 7 or 14 d later or when CGA-362622 was applied first followed by clethodim 7 d later. Reduced control of fall panicum, goosegrass, and large crabgrass was observed, however, when CGA-362622 was applied first followed by clethodim 14 d later. Rather than antagonism, the 14-d reduction in control most likely was caused by reduced effectiveness of clethodim on larger grasses because the 14-d treatments were made onto grasses exceeding the recommended maximum treatment size (20 to 25 cm) for clethodim (Anonymous 2001). The reduction in grass control by clethodim in the field corresponds to the reduction in grass control observed in the greenhouse studies.

Growth Analysis. Data were pooled over trials as there was not a trial main effect. CGA-362622 reduced goosegrass biomass accumulation compared with the nontreated goosegrass from 0 to 4 DAT (Figure 1). Thereafter, the increase of biomass was similar for both CGA-362622–treated and nontreated goosegrass. Orthogonal polynomial contrasts were used to quantify the significance between the growth rates. From 4 to 8 DAT, the growth rates for the treated and nontreated goosegrass were similar. However, the rate of biomass increase of treated goosegrass was less than that of nontreated goosegrass from 0 to 4 DAT (Table 3). These data suggest that CGA-362622 affects one or more physiological processes within goosegrass. Others have found that when ALS-inhibiting herbicides were applied 1 or 2 d before an application of a graminicide, there was a reduction in translocation of the graminicide (Croon et al. 1989; Ferreira et al. 1995). Furthermore, other ALS-inhibiting herbicides have been found to inhibit a number of physiological processes, including photosynthate transport and mitosis (Shaner and Singh 1997).

The reduction in grass control by CGA-362622 and

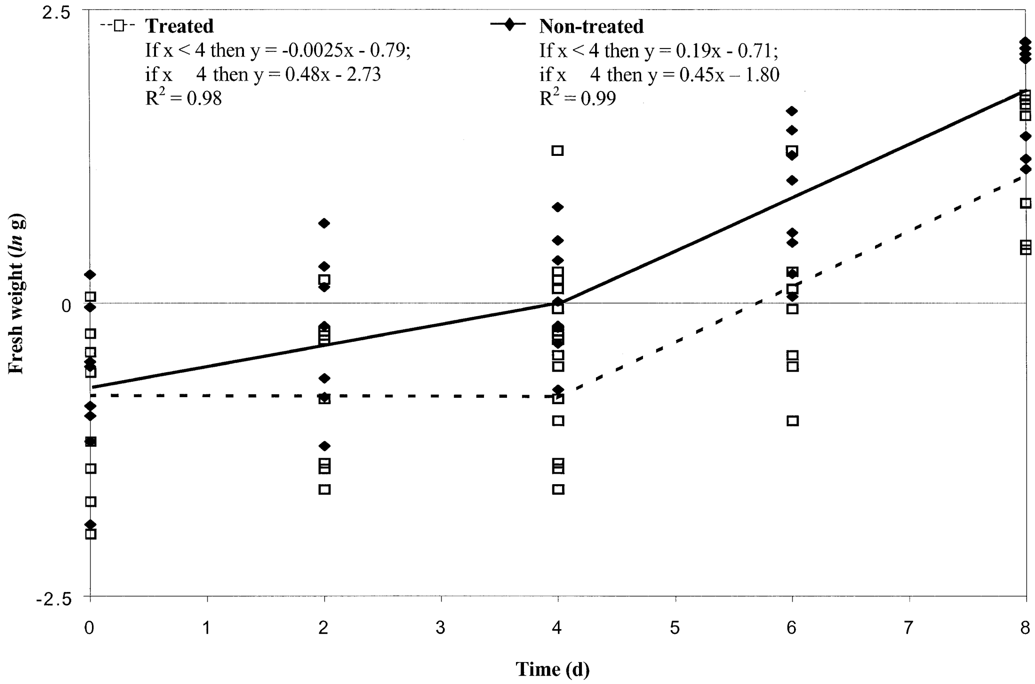

Figure 1. Log-transformed fresh weight (g) accumulation of nontreated goosegrass and goosegrass treated with CGA-262-622 at 5 g ai/ha over time.

clethodim in mixture was greater than that reported for other ALS inhibitors such as chlorimuron or thifensulfuron, or imazethapyr when applied in mixture with cyclohexanedione herbicides (Foy and Witt 1992; Jordan 1995; Myers and Coble 1992; Vidrine et al. 1995). Chlorimuron, when mixed with clethodim or sethoxydim, reduced control of johnsongrass [*Sorghum halapense* (L.) Pers.] and barnyardgrass [*Echinocloa crus-galli* (L.) Beauv.] compared with clethodim or sethoxydim alone, although the reduction in control was inconsistent (Jordan 1995; Vidrine et al. 1995). Chlorimuron did not antagonize broadleaf signalgrass control with clethodim (Jordan 1995; Myers and Coble 1992). Thifensulfuron mixed with sethoxydim reduced control of large crabgrass and giant foxtail (*Setaria faberi* Herrm) compared with sethoxydim alone from 95 to 70% (Foy and Witt 1992). Broadleaf signalgrass control with clethodim was not antagonized by imazethapyr (Myers and Coble 1992) when the two herbicides were applied in mixture, although the lack of antagonism with imazethapyr may be the result of imazethapyr also controlling broadleaf signalgrass (87%) when applied alone (Myers and Coble 1992).

Table 3. Orthogonal contrasts of the growth rate of CGA-362622 treated and nontreated goosegrass from 0–4 DAT[a] and 4–8 DAT.

	0–4 DAT	4–8 DAT
	Δ fresh weight (*ln* g)	
Treated[b]	−0.0025	0.48
Nontreated	0.19	0.45
Statistical analysis		
Mean square	2.30	0.03
P-value	0.0053	0.76

[a] Days after treatment.

[b] CGA-362622 was applied at 5 g ai/ha with 0.25% (v/v) nonionic surfactant.

CGA-362622 antagonized control of broadleaf signalgrass, fall panicum, goosegrass, and large crabgrass when applied in mixture with clethodim. Sequential applications with a minimum of a 7-d interval between treatments were required to overcome this antagonism. This study indicates that clethodim should be applied before CGA-362622 for greatest control of broadleaf signalgrass, fall panicum, goosegrass, and large crabgrass. However, growers should base their decision of which herbicide to apply first on the sizes (and consequent time period for optimum herbicide efficacy at those sizes), densities, and competitive indices of the weeds present in their fields.

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